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RESEARCH ARTICLE

A TUTORIAL OF ROUTING PROTOCOLS IN WIRELESS SENSOR NETWORKS

Rajesh Chaudhary (STUDENT)
CSE Department
Bahra University, Shimla Hills
Himachal Pradesh, INDIA
rajeshchaudhary121989@gmail.com

Dr. Sonia Vatta (GUIDE)
CSE Department
Bahra University, Shimla Hills
Himachal Pradesh, INDIA
soniavatta@yahoo.com

Abstract-- Wireless sensor network is a network that consists of tiny, complex and large number of sensors and at least one base station or sink node. Most challenging issue in wireless sensor network is the limited battery power of sensor nodes used in the network. To increase the energy of sensor nodes, energy is preferably dispensed throughout the wireless sensor network. So the key to enhance the life time of the network is to design effective and energy aware protocols. Routing protocol can be network structure based or protocol operation based. In this paper, a tutorial of existing routing protocols in wireless sensor networks is carried out. Challenging issues for WSNs are Energy consumption and network life time. In the following sections which are described below, we present various existing routing protocols with their merits and demerits.

Keywords-- Routing, base station, energy, sensor nodes, WSN

I. INTRODUCTION

A Wireless sensor network consists of tens to thousands of sensor nodes that are densely deployed in a sensor field and have the capability to gather data and route information back to base station [1]. Now days, Wireless Sensor Network is employed in several application such as detecting and tracking troops, tanks on a battleground, compute traffic flow on roads, compute humidity and other aspects in fields, tracking personnel in buildings. A sensor node includes sensing unit, power unit, and processing unit.

Wireless Sensor Networks characteristics are as follows:

a) Dynamic network topology
b) Power constraint.
c) Do not have global identification.
d) Heterogeneous nodes.
e) Nodes are prone to failures.

II. Wireless sensor network applications

Sensor nodes are employed in various application dependent events that need constant observance and detection [2] [3]. Some of the applications are stated below:

- Battlefield surveillances and monitoring.
- Forest fire and flood detection.

- Inventory control system.
- Green house monitoring.
- Agriculture.
- Personal heath monitoring.
- Detects explosive material, biological, radiological, chemical, nuclear etc.

III. DESIGN ISSUES OF ROUTING PROTOCOLS

Initially WSNs was mainly motivated by military applications for battlefield surveillances. Civilian application domain of wireless sensor networks have been considered later on, such as environmental, healthcare and production , smart home etc. To meet this diversification, the following significant design issues of the sensor network have to be considered:

- *Fault Tolerance:* Fault tolerance is the ability to sustain sensor network functionalities without any interruption due to sensor node failures.
- *Scalability:* Routing protocols must be scalable enough to respond to events like huge increase of sensor nodes in the environment field.
- *Operating Environment:* Sensor nodes may be deployed in any environment conditions.
- *Power Consumption:* Sensor nodes are equipped with limited battery lifetime.
- *Data delivery models***:** Data delivery models determine when the data collected by the node has to be delivered.
- *Data aggregation:* Data from the normal nodes are to be fused and transmitted to the cluster head of the cluster.
- *Quality of Service:* The quality of service means the quality service required by the application.
- *Network Dynamics:* Sensor nodes are further mobile and therefore sensor network is not static.

IV. ROUTING IN SENSOR NETWORKS

In wireless sensor networks, routing is very challenging due to various characteristics that distinguish them from existing communication and wireless ad-hoc networks. Wireless sensor networks are less infrastructure, also wireless links are unreliable. The sensor nodes are densely deployed either within the sink or very close to it and have restricted power, computational capacity and memory. Sensor nodes are very susceptible to failures. Sensor nodes are densely deployed in large numbers. Thus, the primary goal of a WSN is to produce information from sensed data by individual sensor mode by prolonging the life time of WSN. The restricted power of sensor nodes mandates the design of energy-efficient communication protocol. Routing in WSN is a challenging task because it is extremely different from wireless ad-hoc network and cellular network as:

1. Sensor nodes are densely deployed.
2. Sensor nodes have small memory and limited power resources.

In wireless sensor network routing protocols are divided into three main groups:-

1. Flat-based routing protocol
2. Hierarchical routing protocol
3. Location based routing protocol.

- *Flat Routing*

  Every node plays a similar role and sensor nodes collaborate to perform the sensing task.
- *Hierarchical Routing*

  Higher-energy nodes are utilized to process and send the information, whereas low-energy nodes are utilized to perform the sensing within the proximity of the target. The formation of clusters and assigning special missions to cluster heads will greatly contribute to overall network lifetime, and energy efficiency. Hierarchical type of routing is an efficient way to lower the energy consumption within a cluster, performing data aggregation so as to decrease the amount of transmitted messages to the sink node. Nodes may play completely different roles within the network like cluster heads, cluster members in Hierarchical-based routing.

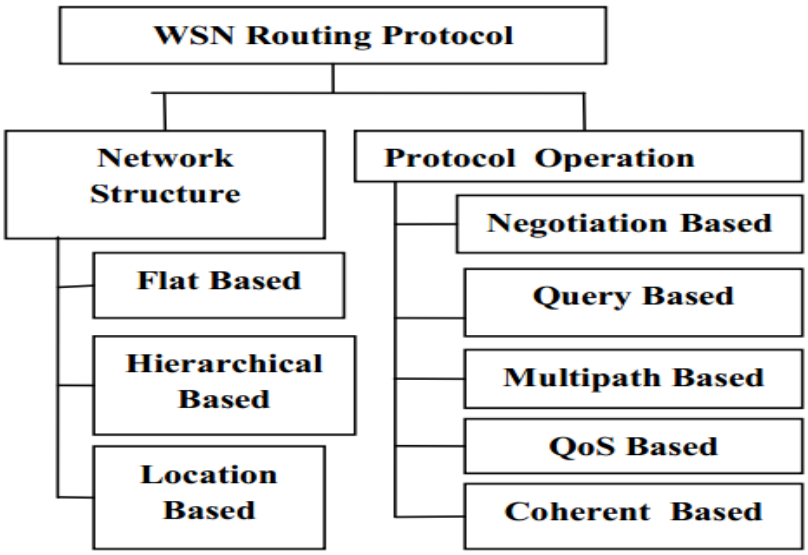

Figure 1: Taxonomy of the routing protocols in WSN

- *Location-based*

Sensor nodes are generally addressed by means of their locations. Between neighboring nodes the distance may be estimated on the basis of incoming signal strengths. In this, relative coordinates of neighboring nodes will be achieved by exchanging such information between neighbors or by communicating with a satellite using GPS. To conserve energy, some location-based schemes required that nodes must go to sleep if there is no activity. In location-based routing, sensor nodes positions are estimated to route data in the network.

A. FLAT ROUTING PROTOCOLS

The first class of routing protocols is that the multihop flat routing protocols. In flat networks, every node usually plays a similar role and further collaborate together to perform the sensing task. This state further led to the data centric routing. In data-centric routing, the sink generally sends queries to the certain regions and waits for data from the sensors located in the selected regions. SPIN is the 1st data-centric protocol .SPIN further considers data negotiation between nodes in order to remove the redundant information and to save the energy [4]. Later after this, Directed Diffusion had been developed. Then, several other protocols have been proposed which is either based on Directed Diffusion or following a same conception [5]. This section describes these protocols in details.

1) SPIN (Sensor Protocols for Information via Negotiation): The plan behind SPIN is to name the data using high level descriptors or meta-data. Meta-data are swapped among sensors before transmission via a data advertisement mechanism, which is the key feature of SPIN. Every node upon receiving new data publicizes it to its neighbors and interested neighbors, means those that don't have the data, retrieve the data or information by sending a request message. SPIN's meta-data negotiation resolves the classic issues of flooding such as redundant information passing, therefore achieves a lot of energy efficiency. There are 3 messages which are defined in SPIN to exchange the data between nodes.
These are: ADV message which generally permits a sensor to advertise a particular meta-data, second is DATA message that carry the actual data and third id REQ message to request the specific data. In SPIN; topological changes are localized since every node needs to know only its single-hop neighbours [4]. Moreover, SPIN doesn't used for applications such as intrusion detection that need reliable delivery of data packets over regular intervals.

2) Directed Diffusion (DD): DD is another protocol which is developed after the SPIN. Directed Diffusion aims at diffusing data through sensor nodes by utilizing a naming scheme for the data. DD utilizes attribute-value pairs for the data and also queries the sensors on the demand basis by using those pairs. In order to make a query, an interest is defined using a list of attribute-value pairs such as objects name, geographical area ,duration, interval, etc. This interest is further broadcast by a sink through its neighbors. Every node which receives this interest can do caching for later use. The nodes also had the flexibility to do in-network data aggregation. The interests in the caches are then used to compare the data received with the values in the interests. The interest entry also contains various gradient fields. This gradient may be a reply link to a neighbor from which the interest was received. Hence, by utilizing interest and gradients, paths are set up between sink and sources. Several paths can be established so that one of them is selected by reinforcement. DD is much energy efficient than others because it is on demand and there is no need for maintaining global network topology [5]. However, it cannot be applied to all sensor network applications because it is based on a query-driven data delivery model [6].

3) Rumor Routing (RR): RR is a compromise between flooding queries and flooding event notifications. The main plan of this protocol is to make paths that leads to every event , unlike event flooding which creates a network-wide gradient field. Thus, in case that a query is generated it can be then sent on a random walk till it discovers the event path, rather than flooding it throughout the network. As soon as the event path is discovered it can be further routed directly to the event. On the other hand, if the path cannot be found, the application may try re-submitting the query or flooding it. The RR may be a good method for delivering queries to events in large networks [7].

B. HIERARCHICAL PROTOCOLS

In this paper various hierarchical based routing protocols has been described. Several researchers carried out their research in the hierarchical routing. A hierarchical approach divides the network into clustered layers. In hierarchical protocols, nodes are grouped into clusters with a cluster head. A cluster head mainly has the responsibility of routing from the cluster to the other cluster heads or to the base stations. Data routes from a lower clustered layer to a higher one. Even though, it hops from one node to another and covers larger distances. This approach moves the data faster to the base station.

1). Low-energy adaptive clustering hierarchy (LEACH): LEACH [8] is the most popular energy-efficient hierarchical clustering algorithm for WSNs that was proposed for reducing power consumption. LEACH relies on an aggregation technique that combines the original data into a smaller size of data that carry only meaningful information to all individual sensors. LEACH splits the network into various clusters of sensors, not only to reduce the amount of data that are transmitted to the sink, but also to make routing and data distribution more scalable and robust. LEACH employs a randomize rotation of high-energy CH position instead of selecting in static manner, so as to provide a chance to all sensors to act as CHs and avoid the battery depletion of an individual sensor and die quickly. LEACH exploits single-hop routing where each node can transmit directly to the cluster-head and the sink. LEACH is further not applicable to networks of large regions. In LEACH, the CHs actually consume a large amount of energy when nodes are located farther away from the sink.

The major advantages of this Protocol are as follow:

- It rotates the cluster heads in a randomized fashion to achieve balanced energy consumption,
- Sensors have synchronized clocks so that they know the beginning of a new cycle,
- Sensors do not need to know location or distance information.

Following are the few shortcomings of LEACH:

- LEACH uses single-hop routing where each node transmits the data directly to the cluster-head and the sink. As a result, it is not applicable to networks deployed in large regions.
- Extra overhead at member nodes.
- Random election of CH, hence there is Possibility that all CHs will be concentrated in same area.
- In LEACH protocol all nodes begin with the same amount of energy capacity in each election round, thus assumes that being a CH it uses up approximately the same amount of energy for each node.

This protocol is most suited for constant monitoring such as monitor machinery for fault detection and diagnosis.

a) Enhanced low-energy adaptive clustering hierarchy (E-LEACH): E-LEACH proposes a cluster head selection algorithm for sensor networks that have non-uniform starting energy level among the sensors. In this, required number of cluster heads has to scale as the square root of the total number of sensor nodes to reduce the total energy consumption.

b) LEACH-Centralized (LEACH-C): LEACH-C uses a centralized clustering algorithm and same steady-state protocol. In this during the set-up phase, each node sends information about current location and energy level to base station (BS). The BS will determine clusters, CH and non-CHs of each cluster. The BS uses the global information of the network to produce better clusters that require less energy for data transmission.

c) Multi-hop LEACH (M-LEACH): M-LEACH modifies LEACH allowing sensor nodes to use multi-hop communication within the cluster in order to increase the energy efficiency of the protocol. It extends the existing solutions by allowing multi-hop inter-cluster communication in sparse WSNs in which the direct communication between CHs or the sink is not possible due to the distance between them. The main idea of the solution proposed here is that the multi-hop approach is followed inside the cluster and outside the cluster. CHs perform data fusion to receive the data thus allows a reduction in the total transmitted and forwarded data in the network.

2) Power efficient gathering in sensor information systems (PEGASIS): PEGASIS is the extension of the LEACH protocol. PEGASIS forms the chain of the sensor nodes so that each sensor node transmits and receives from a neighbour. In this, only one node is choosed from that chain to transmit to the base station (sink). The data is gathered and moves from node to node and eventually sent to the base station. PEGASIS [9] generally avoids cluster formation and uses only one node in a chain to transmit to the BS (sink) instead of using multiple nodes. While in PEGASIS if a sensor fails or dies due to limited power, the chain is again constructed using the greedy approach by bypassing the failed sensor.

a) Hierarchical PEGASIS: An extension to PEGASIS is called Hierarchical-PEGASIS. It was introduced with the objective of decreasing the delay acquired for packets during transmission to the BS. H-PEGASIS proposes a solution to the data gathering problem by considering energy and delay metric.

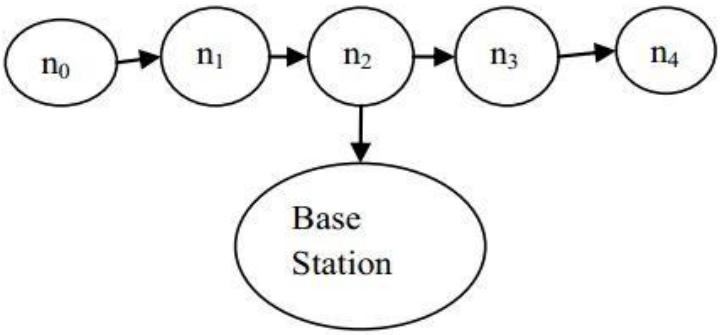

Figure 2: Chaining in PEGASIS

3) Hybrid, Energy-Efficient Distributed Clustering (HEED): HEED also extends the basic scheme of LEACH by utilizing residual energy and node degree as a metric for cluster selection to achieve power balancing. HEED operates in single-hop networks, utilizing an adaptive transmission power in the inter-clustering communication. Four primary goals in HEED are as follows

(i) Prolonging network lifetime by distributing energy consumption (ii) terminating the clustering process within a constant number of iterations (iii) minimizing control overhead, and (iv) producing well distributed CHs and compact clusters.

In HEED [10], the proposed algorithm generally selects the CHs according to a combination of two clustering parameters. The primary parameter is the residual energy of each and every sensor node and the secondary parameter is the intra-cluster communication (i.e. number of neighbors). The primary parameter is actually used to select an initial set of CHs while the secondary parameter is generally used for breaking the ties. Actually HEED clustering improves the network lifetime over LEACH clustering as LEACH generally selects CHs randomly, which might result in faster death of some nodes.

The important features of this protocol are described below:

- HEED extends the lifetime of the nodes within the network thus stabilizing the neighboring node.
- HEED does not require special node capabilities, such as location-awareness etc.
- HEED does not make assumptions about node distribution. The nodes automatically update their neighbour sets in multi-hop networks by periodically sending and receiving messages.
- The nodes only require local (neighborhood) information to form the clusters.

4) Threshold sensitive energy-efficient sensor network (TEEN) Protocol: TEEN is a hierarchical clustering protocol. TEEN protocol groups the sensors into clusters which are led by a CH. The sensors within a cluster broadcast their sensed data to their CH. The CH further sends the aggregated data to higher level CH until data reaches to the sink. Hence, the sensor network architecture in TEEN is actually based on a hierarchical grouping where closer nodes form the clusters which further send their aggregated data to the base station or to the sink. TEEN uses a data-centric method with hierarchical approach.

Major advantages of this protocol are as follows:

- Time critical data reaches the user almost instantaneously.
- Supported by the thresholds, data transmission are often controlled i.e. , only the sensitive data we have a tendency to demand are often transmitted, so as to reduces the energy transmission consumption and improves the effectiveness and utility of the receiving data.
- Small value of the soft threshold gives a more accurate picture of the network, at the cost of increased energy consumption.

5) Adaptive threshold sensitive energy efficient sensor network (APTEEN) Protocol: APTEEN points at both capturing periodic data collections (LEACH) and reacting to time-critical events (TEEN). Thus, APTEEN is a hybrid clustering-based routing protocol that allows the sensor to send their sensed data periodically. CHs also perform data aggregation in order to save energy. APTEEN supports different query types described below:

(i) Historical query, to analyze the past data values (ii) one-time query for taking a snapshot view of the network (iii) persistent queries so as to observe an event for a period of time. In APTEEN, energy dissipation is much lower and therefore large numbers of sensor nodes are alive

6) COSEN: Chain Oriented Sensor Network: COSEN [11] operate in two phases -chain formation phase followed by data transmission phase. In the first which is known as chain formation phase, chains of different levels are formed while in second phase called, data transmission phase, information is transmitted through the designated paths. In COSEN, one higher level chain and several lower level chains are formed with the deployed sensors. In every chain, one node is elected as a leader based on some criteria or measures. Lower level leader nodes collect information from lower level

chains and send the information towards higher level leader. In this, higher level leader sends the information to the BS after getting information from lower level leader.

7) Chain Based Hierarchical Routing Protocol (CHIRON): Chain-based routing is one of the most important among routing mechanisms. In this routing scheme, sensor nodes in WSN are linked into a single or multiple chains in advance. In data dissemination phase, every node communicates just with its closest neighbours, and becomes the chain leader for transmitting the aggregated data to the BS. The chain-based routing protocols can effectively balance the node's energy dissipation, and therefore significantly extend the network life-time. They might cause serious transmission delays and redundant paths while it is used for large sensing areas. Based on the Beam Star [12]concept, the main idea of CHIRON is to split the sensing field into a number of smaller areas, in order to create the multiple shorter chains to reduce the data transmission delay and duplicate path, and therefore effectively conserve the energy of the node and prolong the network lifetime.

In this, the technique of Beam Star is first utilized to divide the sensing area into a number of fan-shaped groups. The sensor nodes within each group are self organized into a chain for data dissemination.

C. LOCATION BASED PROTOCOLS

The location based routing protocol uses location information to guide routing discovery, for maintenance as well as for data forwarding. It further enables directional transmission of the information and avoiding information flooding in the whole network.

Location information is required in order to calculate the distance between two particular nodes so that energy consumption can be estimated and reduced [13].

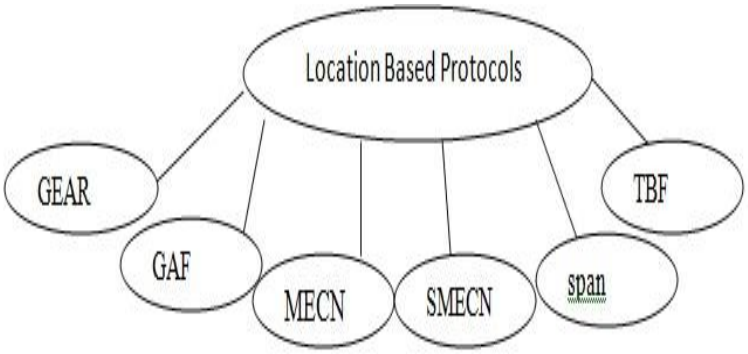

Figure 3: Classification of Location based protocols

1) GEAR: In this, Yu et al. [15] described that each node keeps an estimated cost and a learning cost of reaching the destination through neighbors. The estimated cost is generally a combination of residual energy and distance to destination. Hole generally occurs when a node does not have any closer neighbors to the target. If there are no holes, estimated cost is equal to the learned cost. This cost is propagated one hop back each time when a packet reaches the destination so that route set up for next packet will be adjusted. Benefit of GEAR is not only to reduce energy consumption for the route setup, but it also performs better packet delivery.

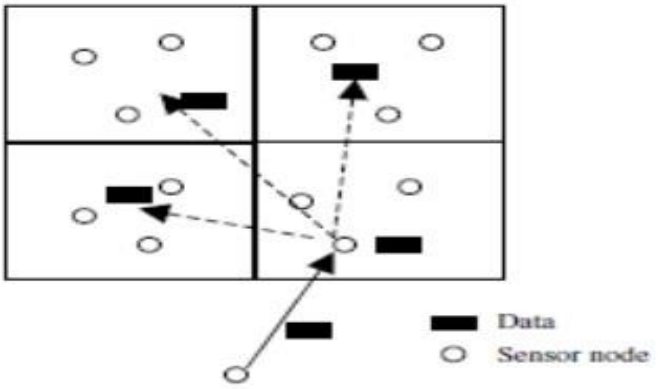

Figure 4: Geographic Forwarding in GEAR

2) Geographic Adaptive Fidelity (GAF): GAF is employed for WSN as it favours energy conversation. The state transition diagram as shown in Figure described below, has three stages such as discovery, active and sleeping [14]. Once a sensor enters the sleeping state, it turns off radio for energy saving .In discovery state, a sensor exchange discovery

messages to learn about other sensors in the grid. In active state, to notify equivalent sensors about its state a sensor periodically broadcast its discovery message to them. GAF performs well as a normal ad hoc routing protocol in terms of latency and packet loss and further increases the lifetime of the network by saving energy in the transmission.

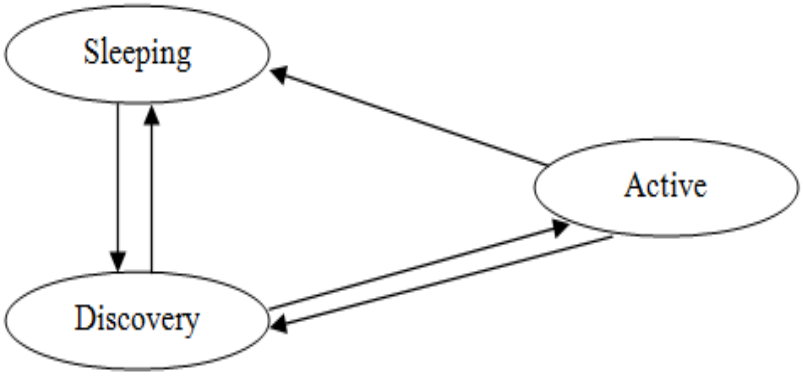

Figure 5: State Transition Diagram of GAF

3) MECN: Minimum energy communication network (MECN) establish and maintains a minimum energy network for wireless networks by utilizing low power GPS. This protocol has 2 phases:

1. It takes the positions of a 2 dimensional plane and constructs a thin graph, that consists of all the enclosures of each transmit node in the graph. The enclose graph contains globally finest links in terms of energy consumption.
2. Finds best possible links on the enclosure graph. MECN utilizes distributed shortest path algorithm with power consumption as a cost metric.

4) SMECN: The small minimum energy communication network (SMECN) is also a modification to MECN. In SMECN protocol; each sensor discovers its immediate neighbors by broadcasting a discovery message with some initial power that is updated incrementally.

Benefit of SMECN is that it uses less energy than MECN and maintenance cost of the links is also less in it but drawback in this is that finding a sub-network with smaller number of edges introduces more overhead in the algorithm.

D. PROTOCOL OPERATION ROUTING PROTOCOLS

In this section, we review routing protocols which are further based on the protocol operation.

1) Multipath-based: They use multiple paths instead of single path so as to reinforce the network performance. For instance, the fault tolerance will be increased by maintaining multiple paths between the source and destination at the expense of augmented energy consumption and traffic generation [4].

2) Query-based: In Query-based protocols, destination nodes propagate a query for data from a node through the network; a node sends the data that matches the query back to the node that initiated it. Examples of this type of routing are DD and RR protocol.

3) Negotiation-based: These protocols use high-level data or information descriptors to remove redundant data transmissions through negotiation. Examples of negotiation-based routing protocols are the SPIN protocols.

4) QoS-based: In QoS-based routing, the network must balance between energy consumption and data quality. The network must satisfy certain QoS metrics (delay, bandwidth, energy etc.) while delivering data or information to the BS. Sequential Assignment Routing (SAR) and SPEED are the examples of this type of protocols.

5) Coherent-based: In coherent routing, data is forwarded to aggregators after processing like time stamping and duplicate suppression. Coherent processing is normally selected in order to perform energy-efficient routing,. Example of coherent data processing is multiple winner algorithms.

6) Non-coherent-Based: In non-coherent data routing, nodes can locally process the raw data before sent to another nodes for further processing. Example of non-coherent data processing is Single Winner Algorithm (SWE).

Routing protocols	Classification	Mobility	Position Awareness	Power Usage	Data Aggregation	QoS	Scalability	Multipath	Query based
SPIN	Flat	Possible	No	Limited	Yes	No	Limited	Yes	Yes
Directed Diffusion	Flat	Limited	No	Limited	Yes	No	Limited	Yes	Yes
Rumor Routing	Flat	Very Limited	No	N/A	Yes	No	Good	No	Yes
LEACH	Hierarchical	Fixed BS	No	Maximum	Yes	No	Good	No	No
PEGASIS	Hierarchical	Fixed BS	No	Maximum	No	No	Good	No	No
TEEN	Hierarchical	Fixed BS	No	Maximum	Yes	No	Good	No	No
APTEEN	Hierarchical	Fixed BS	No	Maximum	Yes	No	Good	No	No
HEED	Hierarchical	Fixed BS	No	Maximum	Yes	No	Good	Yes	No
COSEN	Hierarchical	Fixed BS	No	Maximum	No	No	Limited	No	No
CHIRON	Hierarchical	Fixed BS	No	Maximum	No	No	Good	No	No
GEAR	Location	Limited	No	Limited	No	No	Limited	No	No
GAF	Location	Limited	No	Limited	No	No	Good	No	No
MECN	Location	No	No	Maximum	Yes	No	Low	No	No
SMECN	Location	No	No	Maximum	Yes	No	Low	No	No
SAR	QoS Based	No	No	N/A	Yes	Yes	Limited	No	Yes
SPEED	QoS Based	No	No	N/A	No	Yes	Limited	No	Yes

Figure 6: Comparison and Classification of routing Protocols in wireless sensor networks

V. CONCLUSION

In sensor networks routing is an emerging area of research, which has limited, but rapidly growing set of research results. In this paper, a comprehensive survey of routing techniques in wireless sensor networks has been described. All of them have the common objective of trying to extend the lifetime of the sensor network, whereas on the other side also not compromise with data delivery. Generally, the routing techniques are divided into network structure and protocol operation based routing protocols. In network structure, routing protocols are classified into three categories such as Flat based, hierarchical based and location based routing protocols. Furthermore, some protocols are also classified into multipath-based, negotiation-based, query-based, coherent based, QoS-based and non-coherent based routing techniques based on the protocol operation. In this paper, we have also highlighted the advantages and disadvantages of each and every routing technique.

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